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Electrical Engineering Research Laboratory
The University of Texas

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Propagation of 4.3-Millimeter Radio Waves on 3.5-and 7.0-Mile Paths

Prepared Under Office of Naval Research Contract Nonr 375(01)
NR 071 032

ELECTRICAL ENGINEERING RESEARCH LABORATORY

THE UNIVERSITY OF TEXAS

REPORT NO. 73 | 6 AUGUST 1954

PROPAGATION OF 4.3-MILLIMETER RADIO WAVES ON 3.5- AND 7-MILE PATHS

by

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ABSTRACT

Propagation measurements are reported for frequencies of 69.5 and 70.1 kilomegacycles per second over 3.5- and 7.0-mile paths in the vicinity of Austin, Texas. These measurements indicate that the oxygen absorption is somewhat less than that predicted by Van Vleck [1] whereas the water vapor absorption is several times that predicted.

The magnetron transmitter, the crystal video receiver, and the associated equipment used for the tests are described in the report.

I. INTRODUCTION

The measurements described in this report using a wavelength of 4.3 millimeters are an extension of previous measurements made at 8.6 millimeters [2, 3]. The equipment for the longer wavelength had been so designed that it was readily adaptable to the 4.3-millimeter tests as described later.

A frequency of 69.5 kilomegacycles per second was used on paths 3.5 and 7.0 miles long and a frequency of 70.1 kilomegacycles per second was used on the 7.0-mile path. Data was taken using the 69.5 kmc/s signal for five minute intervals of time on ten days over the 3.5-mile path and on six days over the 7-mile path. Similar samples of data were taken on 70.5 kmc/s on ten days over the 7.0-mile path.

Humidity measurements made at both ends of the path were found to agree satisfactorily with data obtained from the Weather Bureau. By plotting the loss relative to the free space signal level as a function of the water vapor content of the atmosphere it was possible to estimate the loss due to water vapor and that due to oxygen.

The average wet and dry bulb temperature measurements made at the transmitting and receiving sites differed by less than one degree Fahrenheit from the data obtained from the Weather Bureau.

Refractometer measurements were made on a number of days and the spectral distribution of the refractive-index fluctuations is compared to the spectrum of the millimeter fluctuations.

II. RECEIVER

The receiver used to detect the 4.3-millimeter signals was of the crystal video type and is shown in Figure 1.

Through the courtesy of Bell Telephone Laboratories, one of their 5.4-millimeter experimental crystals was made available for use in this receiver. This crystal was of the cartridge type and was mounted in a brass block in such a manner as to allow waveguide to be held in alignment with the windows of the crystal cartridge. One of the sections of waveguide was slotted in the plane of the electric field and a piece of 0.006 inch thick phosphor-bronze was passed through the slot and used as an adjustable shorting stub.

An EH tuner constructed of RG-98/U silver waveguide with shorting stubs of 0.006 inch phosphor-bronze passed through slots in the E and H armes was placed between the crystal holder and the calibrated attenuator.

The antennas used were sectional cylindrical horns that had been designed to have optimum dimensions at 8.6 millimeters.

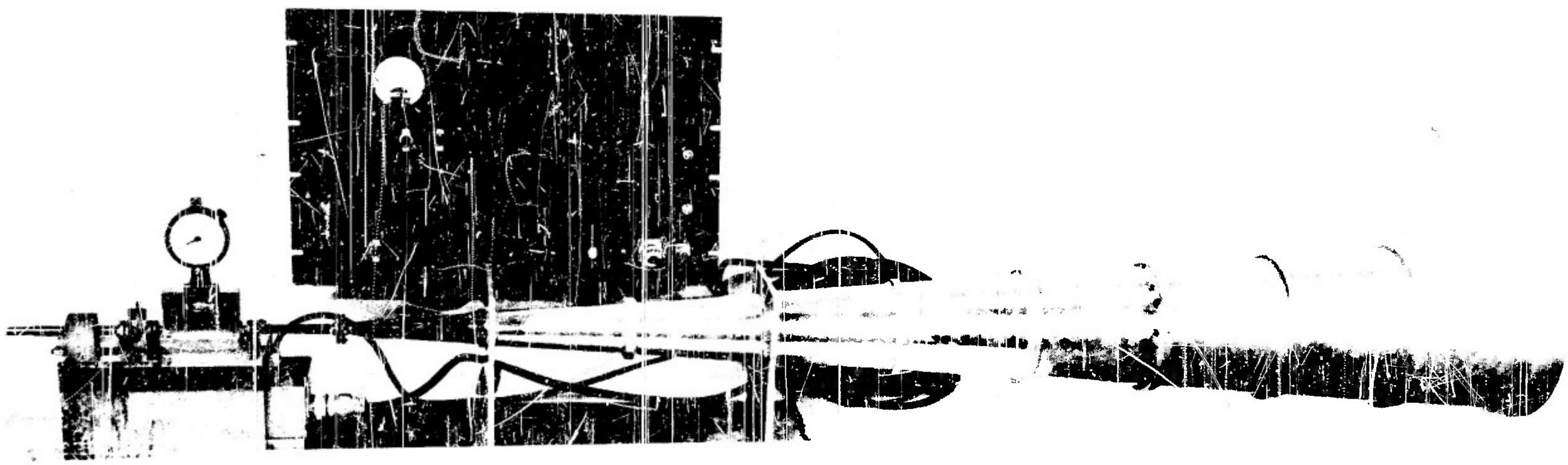
The video amplifier had a bandwidth of 15 megacycles and a minimum detectable signal level of approximately 43 dbm when used with an average video crystal, detecting a 0.25 microsecond pulse at 9.3 kmc/s. The video amplifier was divided into two parts. The pre-amplifier was mounted on the base holding the crystal detector, the EH tuner, the calibrated attenuator, and the antenna. The main body of the amplifier, the integrator, the metering circuits, and the power supply were mounted on a chassis behind a relay rack panel. A 20 foot length of cable was used to couple the pre-amplifier to the main amplifier. A voltage derived from the integrator was supplied back as a bias to the stages of the main amplifier to produce a 20-db-range recording scale.

III. ANTENNAS

The antennas used on the 3.5-mile path consisted of four sections of the conical horn which gave optimum dimensions at 8.6 mm and had an antenna gain of 34 db. The antennas used on the 7-mile path consisted of eight sections of the conical horn with a hyperbolic lens of plexiglass at the mouth to modify the phase front to the extent that an effective capture area of near one was realized. These antennas had a gain of 40.8 db. The antennas used for calibrating the attenuator were single sections of the cylindrical horn so that all spacings between the transmitter and receiver the phase front was essentially plane across the mouth of the antennas.

IV. CALIBRATED ATTENUATOR

The calibrated attenuator was of the guillotine type with a dial gage used to indicate the depth of penetration of the resistance material. The moving parts and the blocks used to assemble the moving parts and the silver waveguide were



VIEW OF CRYSTAL VIDEO RECEIVER

FIG. 1

made of stainless steel. The glass upon which nichrome was evaporated was a 0.005 inch thick microscope slide cover. The glass was cut on an arc whose cord was 1.5 inches with a tantalum-carbide tipped scribe. The nichrome was evaporated on the glass from a tantalum boat at a chamber pressure of 5×10^{-5} millimeters of mercury after the glass had been preheated to a temperature of 200° C. The 400 ohm per square nichrome film was given a protective coating of magnesium fluoride. The glass with its coating of resistance material was cemented in a slot in the guillotine with De Khotinsky cement.

The attenuator was calibrated by varying the spacing between the transmitter and the receiver over such distances as to give known increments of attenuation based on the inverse square law variation of power level. This procedure was repeated a number of times over two different paths and a smooth curve was drawn through the average of the points thus obtained. The maximum deviation of the points from the average was approximately 0.5 db.

V. TRANSMITTER

The signal sources were experimental magnetrons of the Columbia University design operating at frequencies of 69.45 kmc/s and 70.10 kmc/s.

The antennas used on the transmitter were identical with those used at the receiver with the 34 db antenna on the 3.5-mile path and the 40.8 db antenna on the 7-mile path. A view of the transmitter as used on the 3.5-mile path is shown in Figure 2 and a view of the transmitter as used on the 7-mile path is shown in Figure 3. A crystal detector was used to monitor the relative peak power level and the pulse length. Power output characteristics relative to the average magnetron current and filament voltage were determined by measurements made over a 1000 foot path over a period of two weeks.

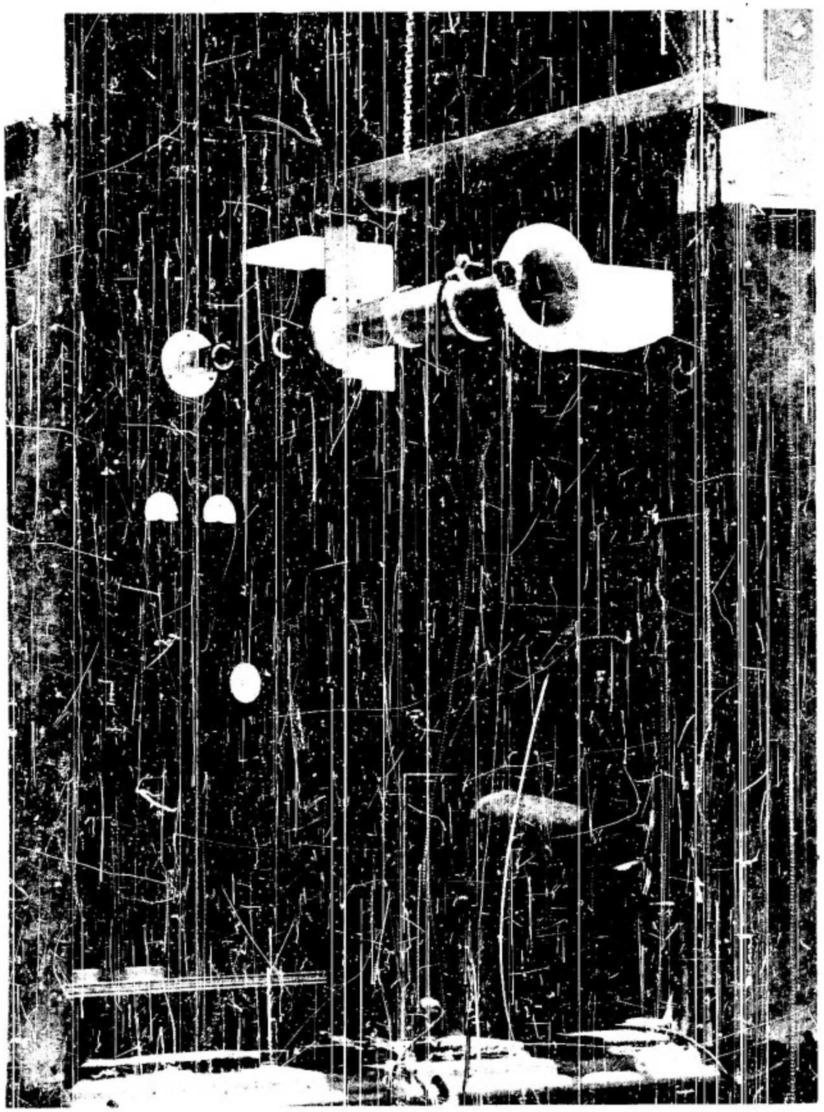
VI. MEASURING PROCEDURE

(a) 1000 foot Path

Measurements were made over a base path whose length was 1000 feet with the transmitter and receiver assembled as they were used on the 3.5-mile and 7-mile paths. Measurements were made at random times during a two week period. The results indicated the signal strength could be measured with an accuracy of ± 0.2 db. The base path also provided a signal level relative to which the signal levels over the 3.5-mile and 7-mile path were measured.

(b) 3.5-mile and 7-mile Paths

The receiver was located on the 25th floor of the University tower for both the 3.5-mile path and the 7-mile path. This location was about 250 feet above ground level and at an elevation of about 850 feet. For the 3.5-mile path, the



VIEW OF TRANSMITTER AS USED
ON 3.5-MILE PATH
FIG. 2

VIEW OF TRANSMITTER AS USED
ON 7.0-MILE PATH
FIG. 3

transmitter was located at the antenna site of KTBC-TV on Mount Larson at an elevation of 910 feet. The ground level dropped off from the University tower, rising abruptly at Mount Larson. A view of this path as seen from the University tower is shown in Figure 4.

For the 7-mile path, the profile elevation increased fairly uniformly from the base of the tower to a value of 810 feet at the Balcones Research Center. The transmitter was located about 10 feet above ground for the measurements. The 7-mile path as seen from the University tower is shown in Figure 5. The path is the same as shown in Figure 3 of Report No. 69 [2].

Telescopic gun sights were attached to the antennas and were used for pointing the antenna each time measurements were made. After alignment, the 4.3-millimeter signal was recorded for a period of three to five minutes on an Esterline-Angus recorder.

Sling psychrometer readings at the transmitter site and at the receiver site were taken each time signal strength data were recorded. These readings were found to agree very closely with data obtained from the Weather Bureau. The difference in the water content of the atmosphere as determined from the psychrometer measurements at the two ends of the path did not exceed 0.5 gram per cubic meter. The average of the values measured at the ends of the path was assumed to be the average over the path.

Recordings were made on a number of the measurement days of the refractive-index fluctuations as given by a Crain refractometer [4]. Simultaneous recordings of temperature fluctuations were also taken using a calibrated thermistor.

VII. DATA

The signal strength and water vapor data are given in Table I. The loss was measured relative to that at 1000 feet and the inverse square loss was removed to make the measurements relative to the free space value. For both paths, the signal to noise ratio was approximately 10 db. The relative measurements were made with an accuracy of ± 0.5 db.

VIII. SEPARATION OF WATER VAPOR AND OXYGEN LOSS

The loss in excess of the free space loss was reduced to a per mile basis and is also shown in Table I. This data was plotted as a function of the water vapor content of the atmosphere and is shown in Figure 6.

The line drawn on the figure is a least square line using all of the data on an equal basis. The root mean square of the signal deviation from this line is 0.04 db. From the y intercept, the oxygen absorption loss is indicated to be 0.8 db per mile and from the slope of the line, the water vapor absorption is indicated to be 0.04 db per mile per gram of water vapor per cubic meter. The deviation of the points from this line are also indicated in Table I.

TABLE I

Signal Strength Data

Frequency 70.10 Kmc/s
Path Length 3.5 miles

Date	Time	Temperature °F	Water Vapor g/m^3	Signal Strength Below Free Space Total db	Signal Strength Below Free Space db/mile	Vertical Deviation from least mean square db/mile	Fluctuation Range db
11 May 1954	1400	80	15.4	4.9	1.40	-.04	1.4
12 May 1954	1045	64	11.2	4.1	1.17	+.03	0.5
13 May 1954	1045	68	10.5	4.2	1.20	-.03	0.3
14 May 1954	1400	79	9.7	3.9	1.12	+.02	0.5
17 May 1954	1400	86	12.8	4.4	1.26	.00	0.5
18 May 1954	1430	87	13.0	4.5	1.29	-.02	1.3
19 May 1954	1400	86	15.7	4.8	1.37	+.00	0.7
20 May 1954	1030	80	14.2	4.7	1.34	-.03	0.6
21 May 1954	1400	83	15.4	4.9	1.40	-.04	0.5
24 May 1954	1030	75	14.6	5.1	1.46	-.13	0.4

Frequency 69.45 Kmc/s
Path Length 3.5 miles

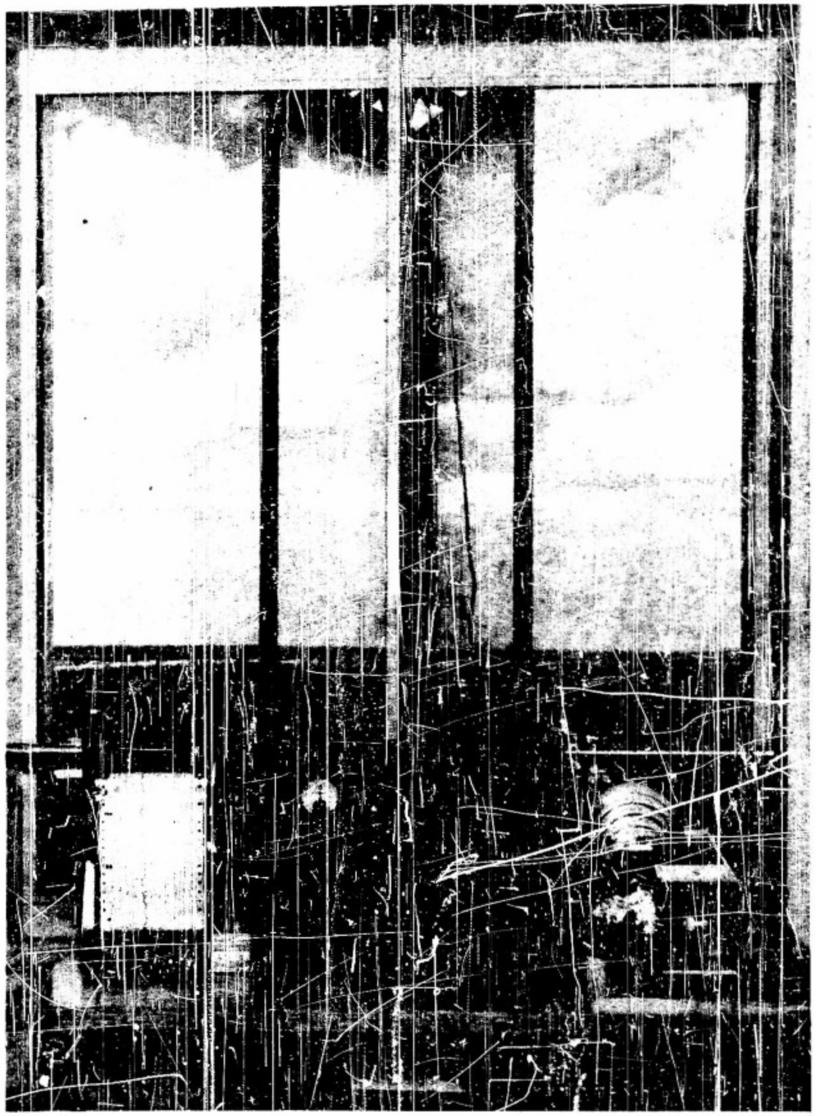
Date	Time	Temperature °F	Water Vapor g/m^3	Total db	db/mile	Vertical Deviation db/mile	Fluctuation Range db
31 May 1954	1530	89	15.7	4.6	1.31	+.06	0.5
1 June 1954	1130	87	18.7	5.2	1.49	-.01	0.7
2 June 1954	1430	93	17.0	5.1	1.46	-.04	0.3
3 June 1954	1030	80	9.1	3.6	1.03	+.09	0.3
4 June 1954	1130	83	9.2	4.1	1.17	-.04	0.3
5 June 1954	1430	89.5	16.0	4.9	1.40	-.02	0.5

Frequency 69.45 Kmc/s
Path Length 7 miles

Date	Time	Temperature °F	Water Vapor g/m^3	Total db	db/mile	Vertical Deviation db/mile	Fluctuation Range db
7 June 1954	1730	89.5	16.0	9.7	1.38	.00	1.8
8 June 1954	1130	89.5	16.2	9.5	1.36	+.03	1.8
9 June 1954	1000	85.5	16.2	9.6	1.37	+.02	2.1
10 June 1954	0930	84.5	17.0	9.5	1.36	+.06	1.4
11 June 1954	1130	89.5	16.2	9.5	1.36	+.03	1.7
14 June 1954	1730	87.5	17.0	9.8	1.40	+.02	2.0
16 June 1954	1130	86	19.0	10.5	1.50	-.01	1.0
18 June 1954	1130	87	17.6	9.8	1.40	+.04	2.2
24 June 1954	0930	85	18.1	10.4	1.49	-.03	1.9
1 July 1954	0930	89.5	16.2	9.7	1.38	+.01	1.4

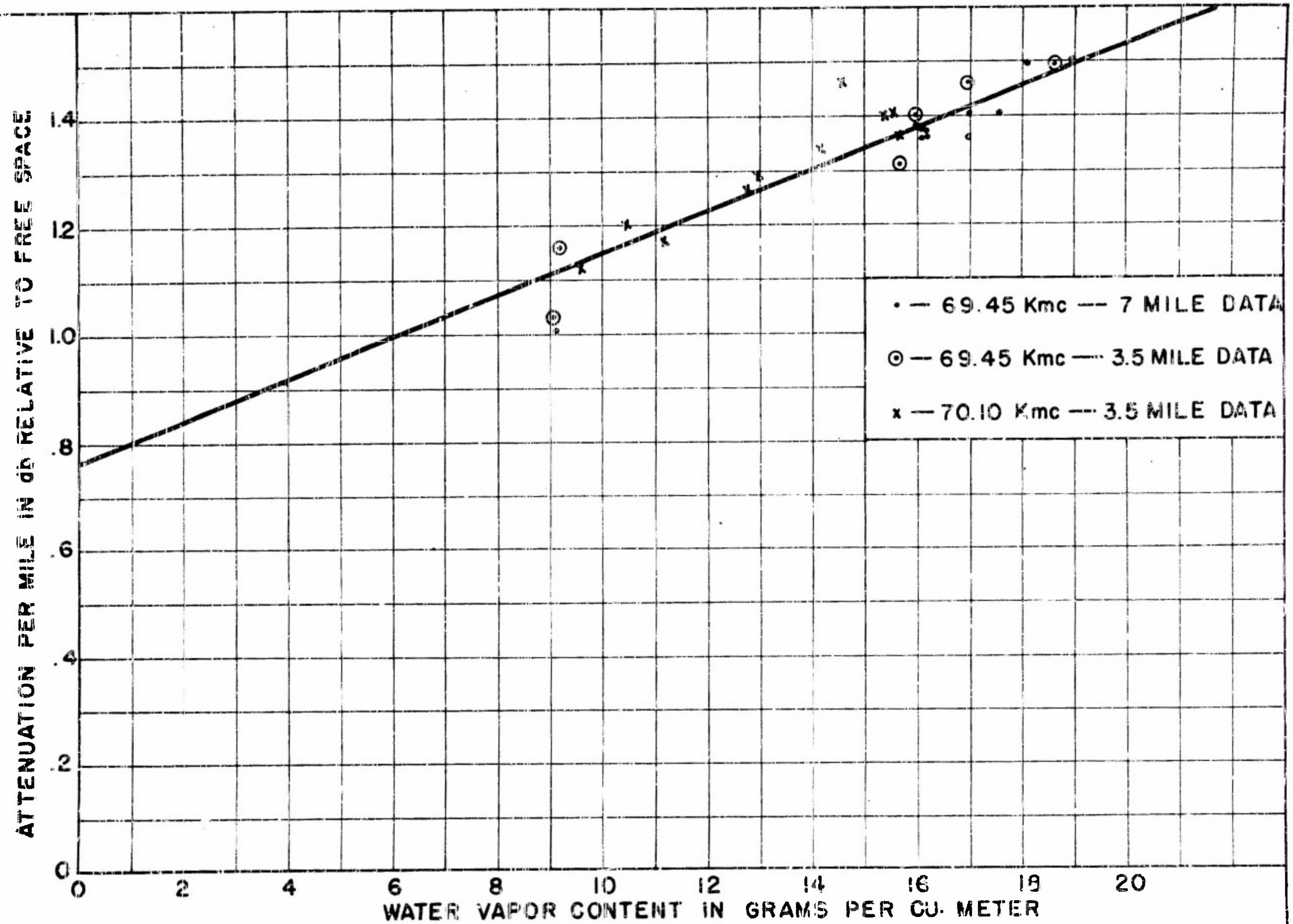
3.5-MILE PATH AS SEEN FROM
UNIVERSITY TOWER

FIG. 4



7.0-MILE PATH AS SEEN FROM
UNIVERSITY TOWER

FIG. 5



LOSS OF RADIO SIGNAL PER MILE vs WATER VAPOR CONTENT

FIG. 6

Because of the limited distribution of the points and because of the limited accuracy of the measurements, separate analysis of the data on the two frequencies did not seem desirable. A comparison of the loss obtained from Figure 6 with those predicted by Van Vleck [1] is as follows:

	Measured	Predicted Theoretical Loss 69.45 Kmc/s	70.10 Kmc/s
Oxygen loss in db/mile	0.80 ± 0.2	1.09	0.95
Water vapor loss in db/mile/gram/m^3	0.04 ± 0.01	0.012	0.012

If a single line breadth constant of 0.26 is used in the formula given in reference [1], the calculated water vapor absorption would agree with the measured value of 0.04 db per mile per gram of water vapor per cubic meter.

From all of the 8.6-millimeter data previously reported, a median loss of 0.017 db per mile per gram of water vapor per cubic meter was found. The line breadth constant of 0.26 is also obtained from these data.

IX. RADIO AND REFRACTIVE INDEX FLUCTUATIONS

The range of signal fluctuations for each sample of data is shown in Table I. The minimum, median, and maximum fluctuation range for the two distances using the 4.3-millimeter wavelength were as follows:

Path Length in miles	3.5	7.0
Minimum Fluctuation Range in db	0.3	1.0
Maximum Fluctuation Range in db	1.4	2.2
Median Fluctuation Range in db	0.5	1.8

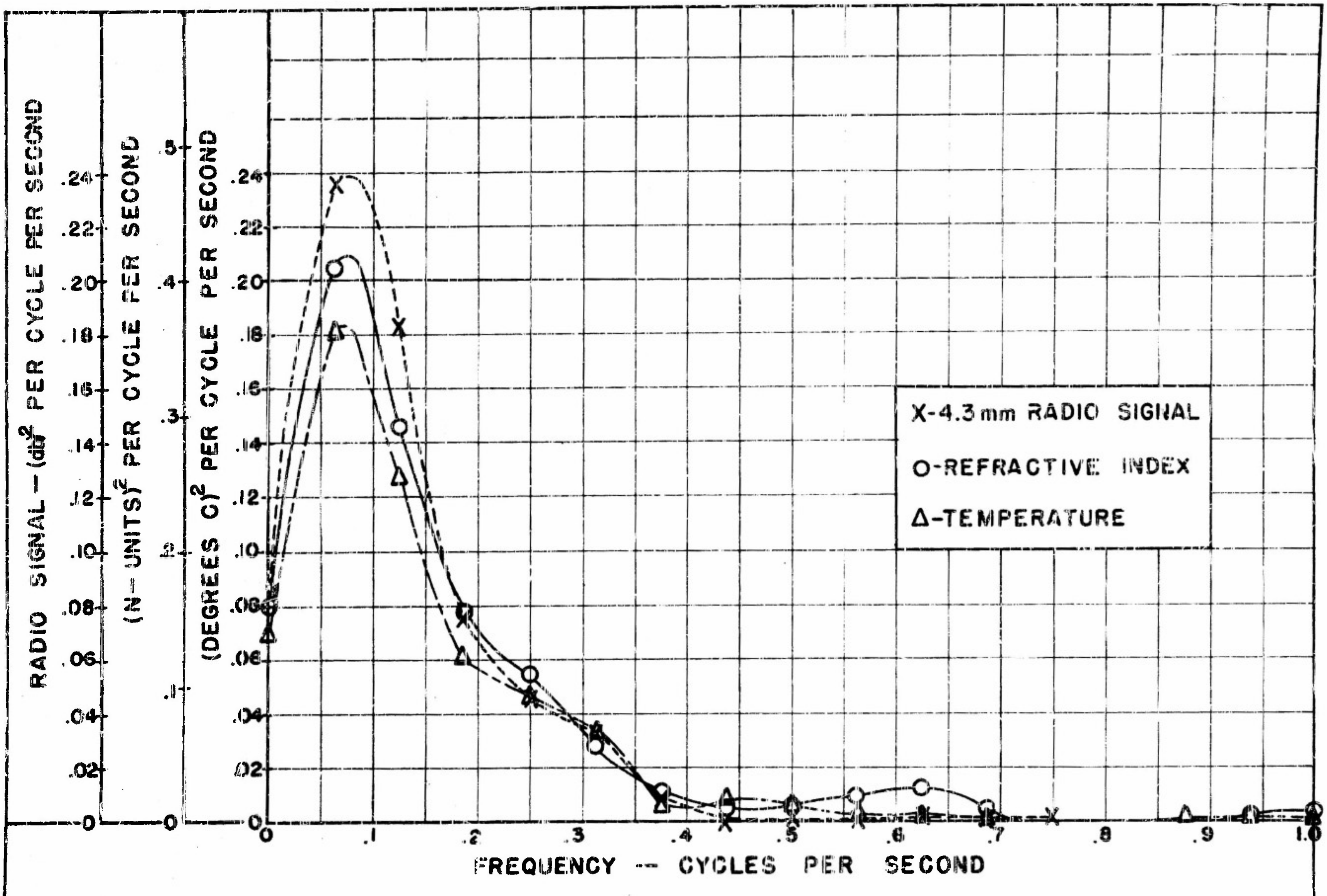
A recording microwave refractometer was set up on top of the transmitting truck and index-of-refraction data were taken simultaneously with the radio data on a number of days. Temperature fluctuations were also measured at the sampling cavity of the refractometer.

For the days on which these simultaneous data were taken, the recordings of radio signal strength, refractive index and temperature were analyzed in the following manner:

1. The statistical distribution of the data was plotted on Gaussian paper and a straight line was drawn through the points.

2. The RMS values of the fluctuations were obtained as one-half of the difference between the 16% and 84% points on these graphs.

3. Autocorrelation functions were plotted using the correlation computer developed by F. E. Brooks [5]. From these, the spectral distribution of the fluctuations were obtained. One set of these spectra is shown in Figure 7. There was



SPECTRAL DISTRIBUTION OF RADIO SIGNAL STRENGTH, REFRACTIVE INDEX, AND TEMPERATURE

FIG. 7

remarkable agreement between the shape of the spectral densities for temperature, index and radio fluctuations in each case.

It should be noted that the length of sample was too short to determine, with any degree of accuracy, the magnitude of the very low frequency contributions. The y intercept point represents the energy in a small interval to the right of the y axis and is somewhat arbitrary in that the average value of the autocorrelation function was made zero. This difficulty does not affect the accuracy of the RMS measurement.

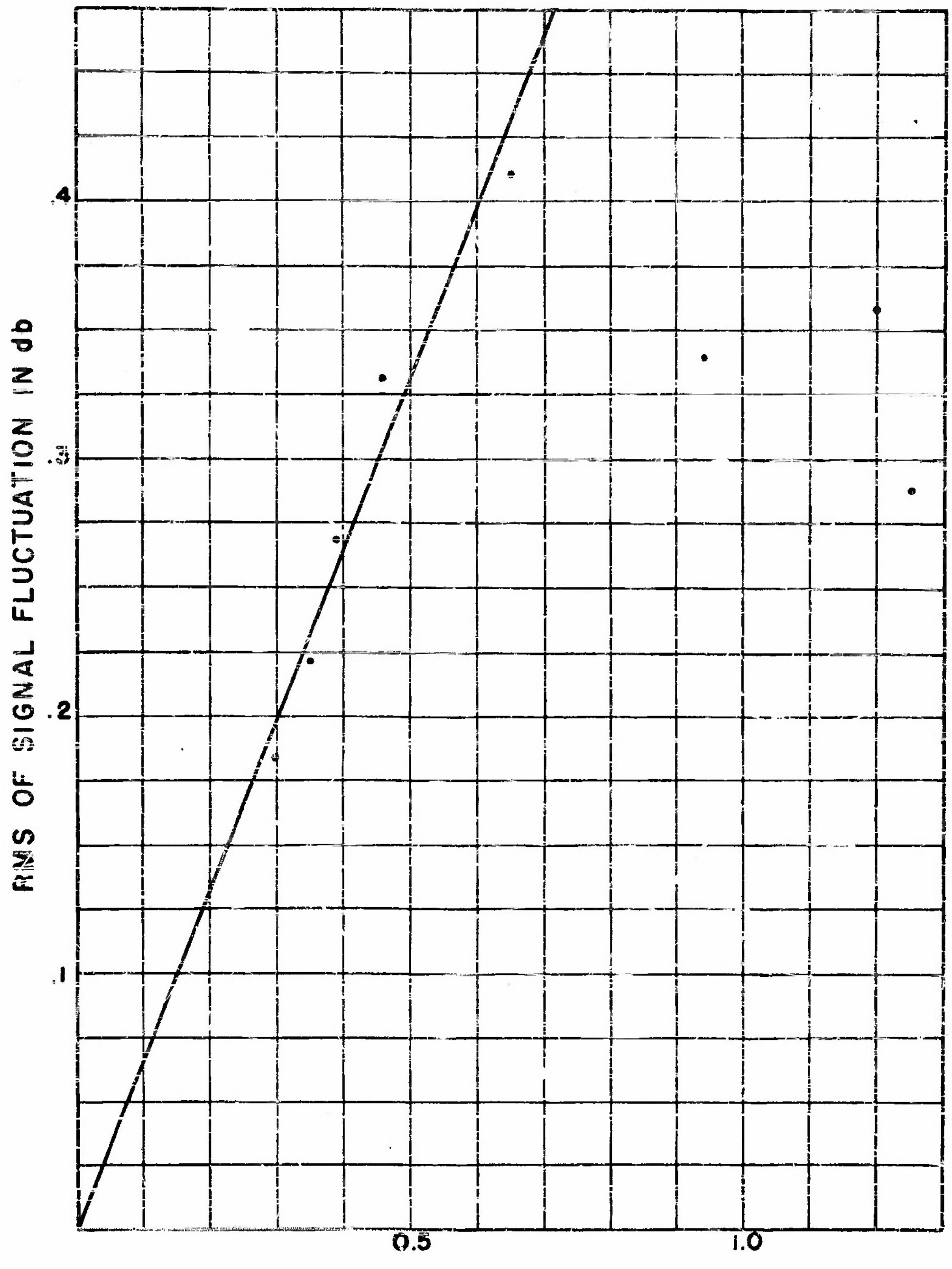
The magnitudes of the RMS values of the fluctuations for data taken on the 7-mile path were as follows:

Date	RMS Radio Signal Fluctuations in db	RMS Index Fluctuations in N units	RMS Temperature Fluctuations in °C
8 June 1954	0.22	0.35	0.11
9 June 1954	0.33	0.46	0.12
10 June 1954	0.18	0.30	0.21
11 June 1954	0.29	1.48	0.11
14 June 1954	0.41	.65	0.17
16 June 1954	0.27	0.39	0.25
18 June 1954	0.34	0.93	0.25
24 June 1954	0.36	1.39	0.14

From these data there appear to be a definite correlation between the magnitude of the radio fluctuations and the magnitude of the index fluctuations. In Figure 8, the RMS values of the signal fluctuations are plotted as a function of RMS values of index-of-refraction fluctuations. The line shown is a least mean square drawn through the origin omitting the three points with the largest index fluctuations.

These three points do not fit the trend of the other points. In each of these three cases, however, there was a slow drift of the index on which the rapid fluctuations were superimposed. This slow drift was the predominant factor in the RMS of the index fluctuation and had no counterpart in the radio signal fluctuations. It is therefore felt that the slow change in index of refraction had little effect on the radio fluctuations, but that the rapid index changes were very closely related to the radio fluctuations.

Another type of signal strength fluctuation was noted over the 1000 foot calibration path when antennas with beam widths of the order of 10 degrees were used. This signal strength fluctuation of 2 db was associated with the wind blowing the 18 inch high grass on the path and was of a much higher frequency than that observed over the longer paths. The signal strength fluctuations over the 1000 foot path were reduced to 0.3 db with the grass uncut by using the 1.7 degree antennas used for measurements over the 7-mile path. The fluctuations were reduced to 0.3 db with the 10° antenna by cutting the grass.



RMS OF RADIO FLUCTUATIONS vs. RMS OF REFRACTIVE INDEX FLUCTUATIONS

FIG. 8

X. COMPARISON WITH 8.6-MILLIMETER DATA

Data were taken in March and April 1953 over the same two paths at a frequency of 35 kmc/s. At this frequency, the absorption loss was much less than for the 4.3 millimeter measurements. The median fluctuation range was, however, approximately the same for the 8.6 millimeter than for the 4.3 millimeters.

A tabular comparison of these data are as follows:

Path Length in miles	3.5	3.5	7.0	7.0
Wave Length in millimeters	4.3	8.6	4.3	8.6
Number of Samples	16	6	10	19
Median Signal Level in db below free space	4.5	0.8	9.7	1.7
Median Fluctuation range	0.5	0.8	1.8	1.0

XI. SUMMARY

Propagation measurements made at frequencies of 69.45 and 70.10 kilomegacycles per second indicated that the absorption loss was approximately that predicted by theory. It was indicated, however, that the measured absorption due to oxygen was somewhat less than the theoretical and that the measured water vapor absorption was several times higher than that predicted by present theory.

Signal level fluctuations are interpreted as being due to index-of-refraction fluctuations.

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